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Petrogenesis of the Ultramafic Complex at the Blashke Islands, Southeastern Alaska

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By GLEN R. HIMMELBERG, ROBERT A. LONEY, and JOHN T. CRAIG

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Petrogenesis of the Ultramafic Complex at the Blashke Islands, Southeastern Alaska

By Glen R. Himmelberg[1], Robert A. Loney, *and* John T. Craig[1]

Abstract

The peridotite-gabbro suite at the Blashke Islands is one of more than 30 Alaskan-type ultramafic complexes exposed along a linear trend in southeastern Alaska. The exposed peridotite-gabbro suite is concentrically zoned and about 3.5 km in diameter. The center of the intrusion is dunite, with wehrlite, olivine clinopyroxenite, and gabbro occurring progressively outward. The ultramafic rocks have textures that are characteristic of cumulates. A contact aureole approximately 100 m wide surrounds the intrusion; the temperature of recrystallization at the contact was about 800 °C. The peridotite-gabbro suite at the Blashke Islands differs from many other Alaskan-type complexes by having minor amounts of orthopyroxene and plagioclase in some ultramafic rocks and by not having magnetite + clinopyroxene cumulates. Field, petrographic, and mineral chemistry data indicate that the peridotite-gabbro suite at the Blashke Islands originated by crystallization differentiation of a subalkaline magma. Accumulation probably occurred in a subvolcanic magma chamber, and the concentric structure was probably caused by upward diapiric emplacement.

INTRODUCTION

The peridotite-gabbro suite exposed at the Blashke Islands, and herein informally called the Blashke Islands peridotite-gabbro suite, is one of more than 30 similar bodies exposed along a linear trend in southeastern Alaska (fig. 1). These bodies generally have been recognized as a separate class of ultramafic instrusions and are referred to as Alaskan-type ultramafic complexes. Most of these complexes have the following characteristic features (Taylor, 1967; Jackson and Thayer, 1972): (1) intrusive contacts having country rocks marked by strong thermal aureoles, (2) rock types that are mostly dunite, wehrlite, olivine clinopyroxenite, magnetite-rich clinopyroxenite, and, in some bodies, gabbro; (3) crude concentric zoning in some of the larger bodies with dunite in the central-most parts and gabbro in the outer-most parts; and (4) principal mineral associations in the ultramafic rocks consisting of olivine, diopsidic pyroxene, magnetite, and hornblende; orthopyroxene and plagioclase are characteristically absent. The Blashke Islands peridotite-gabbro suite differs from the above general description in not having any magnetite-rich clinopyroxenite and by having trace amounts of orthopyroxene and plagioclase in some ultramafic rocks.

Suites of ultramafic, gabbroic, and even dioritic to granodioritic rocks, similar to the Alaskan-type complexes, also have been described in the Klamath Mountains and western Sierra Nevada, California (James, 1971; Snoke and others, 1981, 1982), British Columbia (Findlay, 1969; Clark, 1980), the Urals (Noble and Taylor, 1960; Taylor and Noble, 1960; Taylor, 1967), and Venezuela (Murray, 1972). Although these bodies and the Alaskan-type ultramafic complexes differ in detail, they have many petrologic characterisitics in common, and they are believed to have been formed in a rifted ensimatic arc petrologic-tectonic environment (Snoke and others, 1982). Thus studies of the petrogenesis of these bodies can be instrumental in reconstructing complex petrological processes operating at high crustal levels in arc environments.

The Blashke Islands peridotite-gabbro suite was originally mapped and described by Buddington and Chapin (1929). More complete descriptions were given by Kennedy and Walton (1946) and Walton (1951). The only Alaskan-type ultramafic bodies, except for the Blashke Islands peridotite-gabbro suite, that have been studied in any detail are those at Union Bay (Ruckmick and Noble, 1959) and Duke Island (Irvine, 1974) in Alaska, and at Tulameen (not shown in fig. 1) (Findlay, 1969) in British Columbia.

AGE AND GEOLOGIC SETTING

Preliminary K-Ar dating by Lanphere and Eberlein (1966) suggests an age of 110 Ma for the Blashke Islands peridotite-gabbro suite. They also obtained similar ages (100-110 Ma) for the Duke Island, Union Bay, and Klukwan ultramafic complexes of Taylor (1967) (fig. 1). These ages, which come from widely separated parts of the linear belt of Alaskan-type ultramafic complexes called the Klukwan-Duke belt (Brew and Morrell, 1983), suggest that the complexes were intruded nearly simultaneously.

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The relation of the Klukwan-Duke belt of ultramafic intrusions to the regional geologic framework of southwestern Alaska is shown in figure 1 (modified from Berg and others (1978), Brew and Ford, (1984a), and Brew and others, (1984). The main units from west to east are as follows: (1) the Chugach terrane, composed of mostly flysch and the rest melange consisting of Cretaceous metaflysch and mafic metavolcanic rocks; (2) Wrangellia terrane, composed of Permian and Triassic graywacke, limestone, and mafic metavolcanic rocks; (3) the Alexander belt, composed of coherent, barely metamorphosed Ordovician through Triassic graywacke turbidites, limestone, and volcanic rocks; (4) the Gravina belt, variably metamorphosed and deformed Upper Jurassic to middle Cretaceous flysch and intermediate to mafic volcanic rocks; (5) the Mainland belt composed of commonly metamorphosed and deformed graywacke, pelite, marble, and intermediate volcanic rocks of the Coast plutonic-metamorphic complex of Brew and Ford (1984a); the age is generally unknown, but fossiliferous Carboniferous, Permian, and Triassic rocks are present locally.

As can be seen in figure 1, the Klukwan-Duke ultramafic belt parallels and overlaps the Gravina belt on both sides, and overlaps the Alexander belt on the west and the Mainland belt on the east. Most of the ultramafic complexes intrude in or near the Gravina belt. Important examples that intrude the Alexander belt are the Blashke Islands peridotite-gabbro suite, and to the southeast the Salt Chuck complex of Clark and Greenwood (1972) and the Duke Island complex of Irvine (1974). The Klukwan ultramafic complex intrudes the Mainland belt along trend to the northwest, beyond the end of the Gravina belt in southeastern Alaska. It is evident that the present boundaries of the Gravina belt were not important controls on the movement of magma; instead, it is likely that the chief control was a slightly younger fracture system, probably a tensional one, that only generally paralleled the Gravina belt.

The part of the Alexander belt intruded by the Blashke Islands peridotite-gabbro suite consists of the Descon Formation, which ranges in age from Early Ordovician through Early Silurian (Eberlein and Churkin, 1970). Except where locally metamorphosed as in the contact zone of the Blashke Islands peridotite-gabbro suite, the formation is unmetamorphosed and consists mostly of interbedded graywacke, conglomerate, limestone, shale, and mafic and intermediate volcanic rocks.

DISTRIBUTION AND DESCRIPTION OF ROCK TYPES

The rock classification used in this report is that recommended by the IUGS Subcommission on the Systematics of Igneous Rocks (1973). Most of the rocks have cumulus textures, thus the textural terminology originally established by Wager and others (1960) and Jackson (1967), and more recently redefined by Irvine (1982) is used.

The exposed peridotite-gabbro suite on the Blashke Islands is concentrically zoned and is about 3.5 km in diameter (fig. 2). The center of the intrusion is dunite; wehrlite, olivine clinopyroxenite, and gabbro occur progressively outward. Serpentinization of the olivine-rich rocks ranges from about 25 to 75 percent but original textures are still evident. Contacts between the rock types are generally sharp and almost vertical, although locally they are gradational. The contacts commonly show no evidence of one rock intruding another except for local olivine clinopyroxenite dikes in dunite and gabbro apophyses in olivine clinopyroxenite (Kennedy and Walton, 1946). Walton (1951) also reported dikes of clinopyroxenite with andradite garnet and dikes of hornblendite and anorthosite.

The country rocks are domed and dip steeply away from the intrusion (Walton, 1951). Although the gabbro shows no chill zone against the country rocks, a contact aureole approximately 100 m wide surrounds the intrusion. Most of the rocks within the aureole are massive, fine-grained hornfels with a well-developed granoblastic polygonal texture. The maximum-phase metamorphic mineral association observed is plagioclase-hornblende-orthopyroxene-clinopyroxene-biotite-oxide; this association indicates recrystallization under conditions of the pyroxene-hornfels facies. Chemical compositions of metamorphic orthopyroxene and clinopyroxene in sample 27 projected onto the Lindsley (1983) 1-atm geothermometer yield temperatures of formation of 800 ^{o}C for clinopyroxene and 950 ^{o}C for orthopyroxene. The clinopyroxene temperature is probably the better value since it is less sensitive to analytical error.

Dunite

Dunite, approximately 2 km in diameter, makes up the core of the peridotite-gabbro suite (fig.2) and is the most abundant rock type exposed. It forms massive, homogeneous exposures with no macroscopic internal structures. The dunite is an olivine-chromite cumulate. Clinopyroxene is a minor post-cumulus phase (less than 10 percent) within several meters of the contact with wehrlite, otherwise it is not present. The olivine commonly occurs as 2-3 mm anhedral grains with mutually interfering, gently curved grain boundary segments; euhedral and subhedral grains are also present but are less common. Some olivines show broad kink bands, but generally there is no evidence of strain.

Chromite commonly makes up less than 2 percent of the rock. It occurs as approximately 0.5 mm euhedral grains intergranular to and enclosed in olivine. In some samples, sparse chromite grains in a wispy planar alignment drape over and continue through olvine grains—a textural relation that suggests adcumulus growth of olivine around cumulus chromite "layer". Similar wispy chromite layers are present in the Duke Island Alaskan-type ultramafic complex (Irvine, 1974).

Wehrlite

Wehrlite occurs as a discontinuous unit (as much as 100 m wide) in contact with the western part of the dunite or as arc-shaped lenses within the olivine clinopyroxenite (fig. 2). All exposures are massive and homogeneous; contacts between wehrlite and either dunite or olivine clinopyroxenite are generally abrupt, although gradational contacts are present.

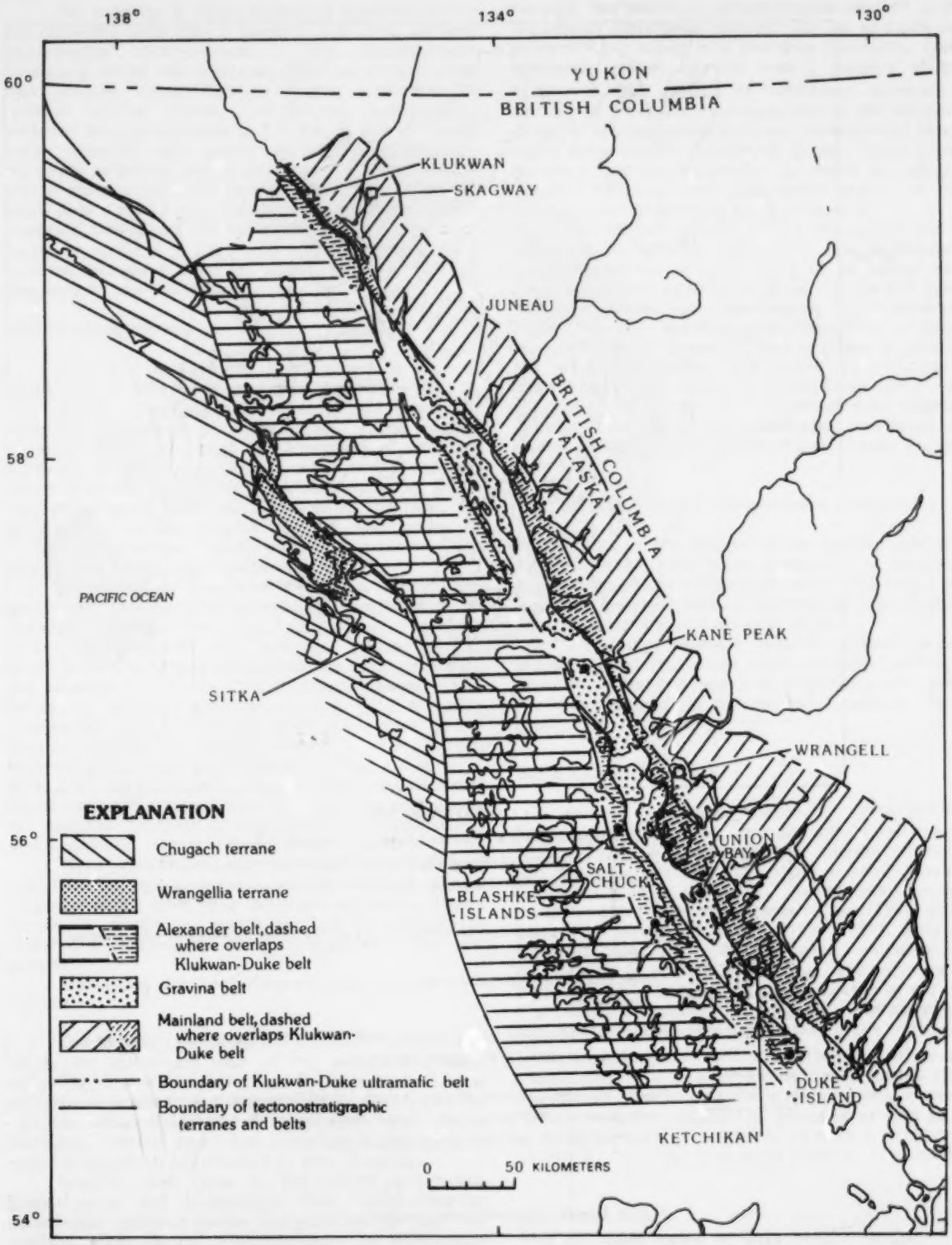
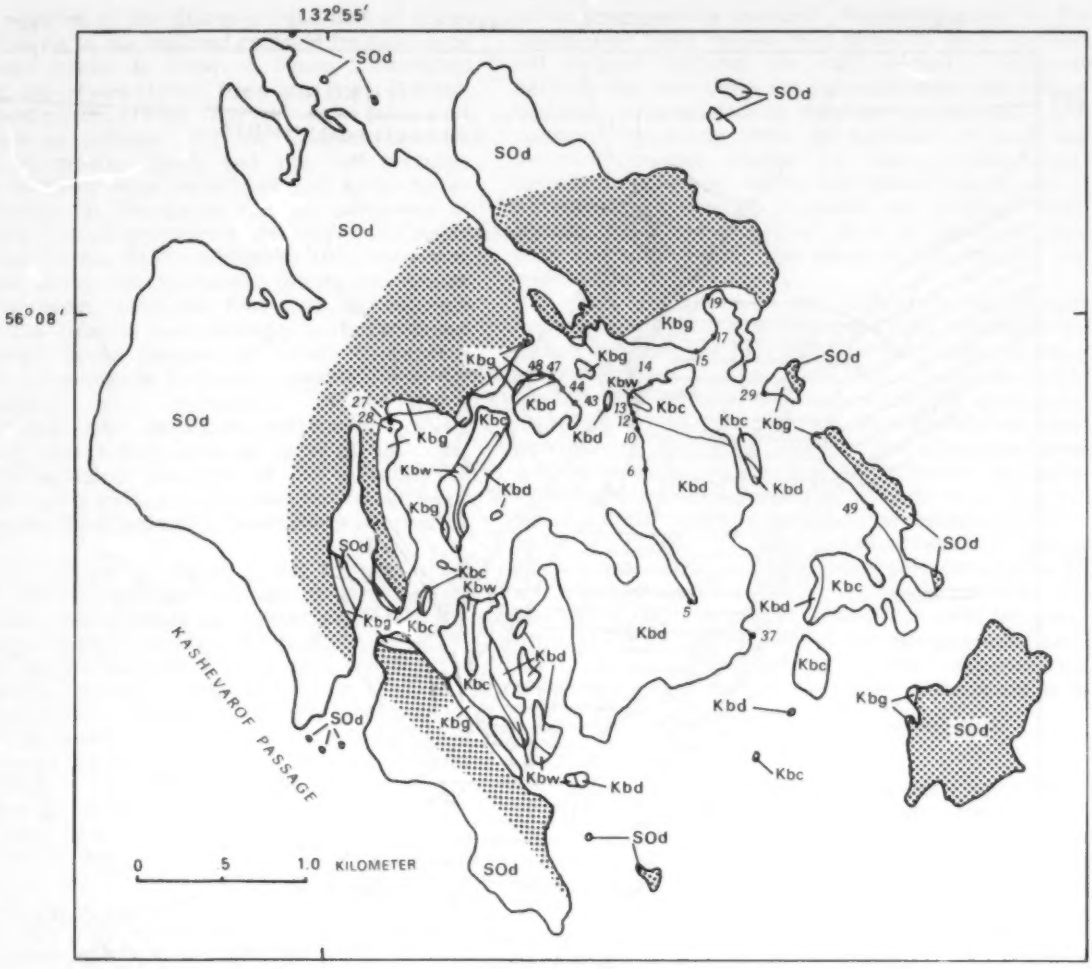


Figure 1. Southeastern Alaska, showing relation of the Duke-Klukwan ultramafic belt to the major tectonostratigraphic framework. Map compiled from Berg and others (1978), Brew and others (1984), and Brew and Ford (1984a). Dots indicate location of Alaskan-type ultramafic complexes.



EXPLANATION

	Peridotite-gabbro suite at Blashke Islands (Cretaceous) — Consists of :
Kbd	Dunite — Composed of olivine and less than 2 percent chromite. Contains as much as 5 percent clinopyroxene near wehrlite or olivine clinopyroxenite contact
Kbw	Wehrlite — Composed of olivine clinopyroxene and chromite. Mineral ratios are extremely variable
Kbc	Olivine clinopyroxenite — Composed of clinopyroxene and olivine. Locally may contain hornblende
Kbg	Gabbro — Transitional from a clinopyroxene gabbro at the ultramafic contact to a hornblende gabbro at the country rock contact
SOd	Descon Formation (Lower Silurian through Lower Ordovician) — Graywacke, conglomerate, limestone, shale, volcanic rocks. Contact-metamorphosed (mostly hornfels) part of unit SOd indicated by stipple
———	Contact
28•	Sample locality — Numbers refer to tables 1 - 7

Figure 2. Geologic map of the peridotite-gabbro suite at the Blashke Islands showing location of analyzed samples (numbers refer to tables 1 through 7). Map modified from Walton (1951).

The wehrlite is characterized by cumulus olivine and chromite (less than 1 percent) and 15-25 percent postcumulus clinopyroxene. The clinopyroxene commonly forms oikocrysts, as much as 1 cm in size, that enclose approximately 1 mm, subhedral to rounded olivine grains. Olivine not poikilitically enclosed in clinopyroxene is 2-3 mm in size and generally anhedral with gently curved grain boundary segments indicating adcumulus growth. Some olivine grains show broad kink bands. Chromite occurs as small (less than 0.5 mm) euhedral and subhedral grains dispersed throughout the rocks either as intergranular grains or included in olivine and clinopyroxene. Rare samples contain a trace of interstitial, postcumulus plagioclase (now rodingite).

Olivine clinopyroxene

Olivine clinopyroxenite forms a unit, as much as about 700 m wide, that encircles the dunite (fig. 2). The olivine clinopyroxenite is composed mostly of cumulus clinopyroxene and olivine. The olivine generally makes up about 10-15 percent of the rock although locally it may be as much as 50 percent. Other minerals include postcumulus hornblende, which may make up as much as 10 percent of the rock, but generally it is less than 1 percent, and traces of biotite, plagioclase, orthopyroxene. chromite, and magnetite are present in some samples.

Clinopyroxene grain size is variable. Most of the grains are 5-7 mm in size although locally, with no regular spatial relation, a finer grained clinopyroxenite, with 2-3 mm size grains, occurs. Some individual grains of the coarser clinopyroxenite are as large as 1.5 cm. The clinopyroxene generally forms an anhedral granular texture with mutually interfering grain boundaries that are either gently curved, sutured, or coarsely irregular. Local areas within a sample have grain boundaries that are straight with 120° intersections. Simple twins and internal replacement of clinopyroxene by magmatic hornblende are common; exsolved orthopyroxene in clinopyroxene is not common. There is no evidence of strain.

The olivine is generally of smaller grain size (1-2 mm) than the pyroxene, but it usually occurs as groups of grains with curved grain boundary segments. Hornblende is mostly intergranular, but it also partly replaces clinopyroxene along margins and cleavage planes.

Gabbro

The gabbro unit is as much as 300 m wide and forms the outermost part of the peridotite-gabbro suite (fig. 2). Much of the unit is characterized by a centimeter-scale flow banding that is manifested by variable concentrations of plagioclase and mafic minerals. Mafic dikes and xenoliths in the gabbro range in size from millimeters to tens of meters.

Specific rock types of the gabbro unit range gradationally and irregularly, from olivine-bearing hornblende-pyroxene gabbro and gabbronorite near the contact with olivine clinopyroxenite to hornblende gabbro toward the outer contact with the country rock. In the hornblende-pyroxene gabbro and gabbronorite, the maximum clinopyroxene content is about 35 percent, the maximum orthopyroxene content is about 5 percent, hornblende content may be as much as 25 percent—only rarely is it less than 5 percent. Olivine commonly makes up less than 1 percent of these rocks. As the amount of hornblende increases the amount of pyroxene decreases, and in the hornblende gabbros, clinopyroxene is absent or restricted to small relict cores in some hornblende grains. Other primary minerals include magnetite (as much as about 15 percent), biotite, and interstitial quartz in some samples, and accessory sphene and apatite.

The gabbros consist of 2-3 mm grains that are subhedral to anhedral granular. The hornblende is generally brown; in some samples individual grains grade irregularly outward to green. In the hornblende-pyroxene gabbro and gabbronorite, the hornblende is present as thick mantles around pyroxene, as internal replacements of pyroxene, and as discrete grains; in the hornblende gabbro, it is present as prismatic and subophitic grains, some of which have relict clinopyroxene granules. Orthopyroxene-magnetite symplectites, which are commonly associated with olivine, probably are a result of a late stage magmatic reaction:

olivine + melt = orthopyroxene + magnetite

Plagioclase in the gabbro shows marked concentric zoning. Some hornblende gabbros have plagioclase with partly altered, embayed cores, and broad clear rims that probably reflect reaction of original plagioclase primocrysts with residual liquid.

Secondary minerals include epidote, chlorite, actinolite, calcite, white mica, prehnite, and hydrogrossular. Small amounts of pyrrhotite and chalcopyrite are present in the olivine clinopyroxenite and gabbro.

MINERAL CHEMISTRY

Olivine, clinopyroxene, orthopyroxene, hornblende, plagioclase, and chromite were analyzed with an ARL EMX-SM[1] electron microprobe; natural and synthetic minerals and oxides of known composition were used as standards. Corrections were made using the procedures of Bence and Albee (1968) and the correction factors of Albee and Ray (1970). Structural formulas for all minerals were calculated by normalizing to number of cations. For pyroxene and chromite, Fe^{2+} and Fe^{3+} were calculated by assuming a perfectly stoichiometric formula. For hornblende, the chemical and crystal-chemical limits outlined by Robinson and others (1982) are satisfied in all cases by normalizing to a total of 13 cations exclusive of Ca, Na, and K. For some hornblende analyses, a suitable formula was also obtained by assuming all iron as FeO or by normalizing to a total of 15 cations exclusive of Na and K. Thus the hornblende formulas presented are

[1]Use of trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

averages of the two calculations that fall within the chemical and crystal chemical limits. The Fe^{2+} and Fe^{3+} in hornblende were then estimated by assuming a total of 46 charges.

The IUGS classification of the analyzed samples, along with a listing of the cumulus and postcumulus minerals, are given in table 1. Locations of the samples are shown in figure 2.

Olivine

Chemical compositions and structural formulas of olivine in the Blashke Islands peridotite-gabbro suite are given in table 2. The compositional range of olivine within a rock unit is very small and shows no relation to position in the unit. There is, however, a systematic decrease in Fo content (100 Mg/(Mg+Fe+Mn)) through the rock series dunite (90.2 to 87.5), wehrlite (87.6 to 87.2), olivine clinopyroxenite (87.6 to 80.4), and gabbro (76.6) that is consistent with fractional crystallization. The Fo values, as well as minor element contents, are similar to those reported for other Alaskan-type ultramafic complexes (Ruckmick and Noble, 1959; Findlay, 1969; Irvine, 1974; Clark, 1980).

Pyroxene

Chemical compositions and structural formulas of clinopyroxene and orthopyroxene are given in tables 3 and 4 and are plotted in the conventional pyroxene quadrilateral (fig. 3). Most of the clinopyroxenes are diopside; the Ca-values (100 Ca/(Ca+Mg+Fe)) of clinopyroxene in the ultramafic rocks are high and range only from 49.9 to 46.7. Clinopyroxene in gabbro generally has equally high Ca-values although one sample is 43.3. The clinopyroxenes show a very limited iron enrichment. The Mg-value (100 Mg/(Mg+Fe+Mn)) of clinopyroxene in the ultramafic rocks ranges from 94.6 to 86.3; clinopyroxene in gabbro extends the range to 75.2. The Al_2O_3 content of clinopyroxene ranges from 0.70 to 2.87 weight percent, it is lowest in postcumulus clinopyroxene in dunite but otherwise there is no relation to rock type. The TiO_2 and Na_2O contents of clinopyroxene range from 0.03 to 0.50 weight percent and 0.02 to 0.37 weight percent respectively; the lowest values are in dunite and the highest values in gabbro.

In terms of CA:Mg:Fe variation the clinopyroxene in the Blashke Islands peridotite-gabbro suite is similar to clinopyroxene in the Alaska-type complexes at Union Bay and Duke Island, Alaska (Ruckmick and Noble, 1959; Irvine, 1974) and Tulameen, British Columbia (Findlay, 1969). The high Ca-values and limited iron enrichment trend are different from the pyroxene trends in tholeiitic intrusions (Wager and Brown, 1968; Atkins, 1969; Himmelberg and Ford, 1976) but similar to pyroxene trends in alkalic intrusions (Irvine, 1974). In terms of Al_2O_3 content, however, the clinopyroxene in the Blashke Islands intrusion differs appreciably from the clinopyroxene in other Alaskan-type ultramafic complexes. In the Union Bay, Tulameen, and Duke Island intrusions, Al_2O_3 values in some clinopyroxenes are as low as in the Blashke Islands clinopyroxene, but most values are higher, commonly between 3.0 and 4.5 weight percent, and some values are as much as 6 percent. Considering all chemical variations, the clinopyroxene in the Blashke Islands intrusion more closely resembles those in the Emigrant Gap mafic complex (James, 1971) in California and in the composite calc-alkaline pluton at Yakobi Island, Alaska (Himmelberg and Loney, 1985).

Orthopyroxene in three gabbro samples of the Blashke Islands peridotite gabbro suite have Mg-values that range from 73.0 to 58.3 and Al_2O_3 contents that range from 1.25 to 2.08 weight percent. The orientation of the tie-line between clinopyroxene and orthopyroxene in sample 28 indicates that these two pyroxenes did not obtain or retain equilibrium compositions. Trace amounts of orthopyroxene were observed in samples of wehrlite and olivine clinopyroxenite but none was analyzed. Orthopyroxene has not been reported in the ultramafic rocks of other Alaskan-type ultramafic complexes but it is present in the Emigrant Gap, California, ultramafic rocks, and these rocks have many similarities with the Alaskan-type complexes (James, 1971). Orthopyroxene is present in the gabbroic rocks at Duke Island, Alaska, but these rocks are older than the ultramafic complex (Irvine, 1974).

Hornblende

Chemical compositions and structural formulas of magmatic hornblende in one sample of olivine clinopyroxenite and six samples of gabbro are given in table 5. The Mg-value of hornblende in the olivine clinopyroxenite is 85.7; the Mg-value of hornblende in gabbro ranges from 77.6 to 63.7. Except for sample 28, the Mg-value of hornblende is highest in the hornblende-pyroxene gabbros and lowest in the hornblende gabbros. There are small variations in the number of Si cations, the number of A-site cations, and the $Fe^{3+}/(Fe^{3+} + Al^{VI})$ ratio. In sample 19 where the hornblende is gradationally zoned from a brown core to a green rim, the later crystallizing green hornblende is silicon-enriched. A similar chemical zonation is present in hornblende in gabbro of the Yakobi Island calc-alkaline pluton (Himmelberg and Loney, 1985).

Plagioclase and chromite

Plagioclase compositions and structural formulas given in table 6 are average compositions of unaltered grain cores. The compositions range from about $An_{82.2}$ to $An_{53.9}$. In general, the more anorthitic plagioclase is present in gabbro near the contact with olivine clinopyroxenite and the albite component increases outward. The albite-enrichment of plagioclase, however, does not exactly parallel the iron-enrichment of amphibole. Most plagioclase show marked oscillatory zoning and distinct Na-enriched rims, which in some samples are albite.

Accessory chromite in the Blashke Islands ultramafic rocks is characterized by high $Fe^{3+}/(Cr+Al+Fe^{3+})$ ratios (0.19–0.26) (table 7) which are typical of chromite in Alaskan-type ultramafic complexes (Irvine, 1967; 1974). The Cr/(Cr+Al) is also relatively high (0.71–0.51) and generally decreases from the dunite core outward.

Table 1. IUGS classification, cumulus minerals, and postcumulus minerals in analyzed samples from the peridotite-gabbro suite at the Blashke Island.

[Sample locations shown on figure 2. Cumulus and postcumulus minerals listed in order of decreasing abundance]

Sample No.	IUGS classification	Cumulus minerals	Postcumulus minerals
37	Dunite	olivine-chromite	--
5	Dunite	olivine-chromite	--
6	Dunite	olivine-chromite	--
43	Dunite	olivine-chromite	clinopyroxene
10	Dunite	olivine-chromite	clinopyroxene
12	Dunite	olivine-chromite	clinopyroxene
47	Wehrlite	olivine-chromite	clinopyroxene-plagioclase
44	Wehrlite	olivine-chromite	clinopyroxene
13	Olivine clinopyroxenite	clinopyroxene-olivine-chromite	--
48	Olivine clinopyroxenite	clinopyroxene-olivine	--
14	Olivine clinopyroxenite	clinopyroxene-olivine	hornblende
49	Gabbronite	non-cumulate	--
15	Hornblende-pyroxene gabbro	non-cumulate	--
29	Hornblende-pyroxene gabbro	non-cumulate	--
28	Olivine-bearing hornblende gabbronorite	non-cumulate	--
19	Hornblende gabbro	non-cumulate	--
17	Hornblende gabbro	non-cumulate	--
27	Two-pyroxene hornfels	--	--

Table 2. Chemical compositions and structural formulas of olivine in the peridotite-gabbro suite at the Blashke Islands.

[Total iron as FeO; - , not detected]

	Dunite						Wehrlite		Olivine clinopyroxenite			Gabbro
Sample No.	37	5	6	10	43	12	44	47	13	40	14	15
SiO_2	42.0	41.1	41.4	41.1	40.8	41.1	41.4	40.3	41.4	40.5	38.7	39.0
FeO	9.51	10.5	10.5	10.6	10.4	11.9	11.9	12.4	12.0	12.7	17.9	20.9
MnO	-	.02	.02	.03	-	.07	.07	.03	.02	.20	.28	.77
MgO	49.4	48.1	48.2	48.6	47.9	47.2	47.2	47.5	47.4	46.2	41.9	39.8
CaO	.17	.26	.21	.05	.18	.08	.08	.09	.07	.47	.37	.17
NiO	.1	.09	.09	.10	.07	.04	.11	.04	.04	-	-	.09
Sum	101.18	100.07	100.42	100.48	99.35	100.39	100.76	100.36	100.93	100.07	99.15	100.73
	Formula per 3 cations											
Si	1.017	1.011	1.015	1.006	1.010	1.014	1.019	0.994	1.016	1.007	0.994	1.00[illegible]
Fe^{2+}	.193	.216	.215	.217	.215	.246	.245	.256	.246	.264	.385	.449
Mn	-	.001	.001	.001	-	.001	.001	.001	.001	.004	.006	.017
Mg	1.784	1.764	1.762	1.773	1.768	1.736	1.731	1.746	1.734	1.712	1.605	1.525
Ca	.004	.007	.006	.001	.005	.002	.002	.002	.002	.013	.010	.005
Ni	.002	.002	.002	.002	.001	.001	.002	.001	.001	-	-	.002
$\frac{100\ Mg}{(Mg+Fe+Mn)}$	90.2	89.1	89.1	89.1	89.2	87.5	87.6	87.2	87.6	86.5	80.4	76.6

Table 3. Chemical compositions and structural formulas of clinopyroxene in the peridotite-gabbro suite at the Blashke Islands.

[Total iron as FeO; Fe^{3+}, Fe^{2+}, Fe_2O_3, and FeO calculated by assuming stoichiometry. –, not detected; n.d., not determined]

	Dunite			Wehrlite	Olivine clinopyroxenite			Gabbro					Hornfels
Sample No.	12	43	10	47	48	13	14	28	17	15	29	49	27
SiO_2	55.2	54.8	53.4	53.2	53.8	54.3	52.3	53.2	53.8	52.2	53.0	52.1	53.0
Al_2O_3	.70	.91	1.49	2.87	1.91	1.61	2.87	2.12	1.86	2.24	1.98	2.35	.88
TiO_2	.10	.06	.03	.25	.17	.13	.26	.24	.24	.30	.25	.50	.16
Cr_2O_3	.17	.09	.05	n.d.	.32	.30	.23	n.d.	.30	–	n.d.	n.d.	n.d.
FeO	1.72	2.43	2.64	3.72	2.95	3.45	4.41	4.58	5.79	7.96	7.76	8.47	9.97
MnO	.05	.06	.05	.09	.11	.09	.13	.12	.43	.48	.56	.41	.35
MgO	17.6	17.4	17.9	16.7	17.5	17.4	16.0	16.3	14.7	14.5	14.2	15.2	14.1
CaO	25.7	24.8	24.8	23.4	23.7	23.6	23.7	23.4	23.4	22.4	22.3	21.2	21.0
Na_2O	.02	.03	.06	.22	.17	.17	.18	.16	.36	.35	.48	.37	.24
Sum	101.26	100.58	100.42	100.45	100.63	101.05	100.08	100.12	100.88	100.43	100.53	100.60	99.80
FeO	1.72	2.43	–	3.00	2.02	3.00	2.98	4.05	5.79	5.96	6.77	6.40	9.51
Fe_2O_3	–	–	2.93	.81	1.03	.48	1.60	.58	–	2.23	1.08	2.31	.50
New Sum	101.26	100.58	100.71	100.54	100.73	101.08	100.25	100.17	100.88	100.66	100.62	100.84	99.84
	Formula per 4 cations												
Si	1.980	1.981	1.927	1.928	1.942	1.956	1.911	1.944	1.969	1.926	1.954	1.916	1.982
Al^{IV}	.020	.019	.063	.072	.058	.044	.089	.056	.031	.074	.046	.084	.018
Al^{VI}	.010	.020	–	.051	.023	.024	.035	.035	.049	.023	.040	.018	.021
Ti	.003	.002	.001	.007	.005	.004	.007	.007	.007	.008	.007	.014	.004
Cr	.005	.003	.001	n.d.	.009	.009	.007	–	.009	–	n.d.	n.d.	n.d.
Fe^{3+}	–	–	–	.022	.018	.013	.044	.016	–	.062	.030	.064	.014
Fe^{2+}	.052	.073	.084	.091	.061	.091	.091	.124	.177	.184	.209	.197	.298
Mn	.002	.002	.002	.003	.003	.003	.004	.004	.013	.015	.017	.013	.011
Mg	.941	.938	.963	.902	.942	.934	.872	.888	.802	.797	.780	.833	.786
Ca	.988	.961	.959	.909	.917	.911	.928	.916	.918	.885	.881	.835	.841
Na	.001	.002	.004	.015	.012	.012	.013	.011	.026	.025	.034	.026	.025
100 Mg/(Mg+Fe+Mn)	94.6	92.6	92.2	88.6	91.1	89.7	86.3	86.0	80.8	75.3	75.3	75.2	70.9
Ca	49.9	48.7	47.9	47.2	47.1	46.7	48.0	47.1	48.4	45.9	46.4	43.3	43.4
Mg	47.5	47.6	48.1	46.9	48.4	47.9	45.1	45.7	42.3	41.3	41.1	43.2	40.5
Fe	2.6	3.7	4.0	5.9	4.6	5.3	7.0	7.2	9.3	12.8	12.6	13.5	16.1

Table 4. Chemical compositions and structural formulas of orthopyroxene in the peridotite-gabbro suite at the Blashke Islands.

[Total iron as FeO; Fe^{3+}, Fe^{2+}, Fe_2O_3, and FeO calculated by assuming stoichiometry]

	Gabbro			Hornfels
Sample No.	13	49	28	27
SiO_2	54.1	54.1	52.9	52.2
Al_2O_3	2.08	1.66	1.25	0.76
TiO_2	.21	.20	.13	0.15
FeO	16.2	16.6	23.7	24.4
MnO	.90	.77	.83	0.76
MgO	25.9	25.9	20.6	19.7
CaO	1.55	1.34	1.47	1.71
Na_2O	.04	.04	.05	0.07
Sum	100.98	100.61	100.93	99.75
FeO	15.7	16.0	23.7	24.0
Fe_2O_3	.55	.67	-	0.46
New Sum	101.03	100.68	100.93	99.81
Formula per 4 cations				
Si	1.943	1.953	1.971	1.977
Al^{IV}	.057	.047	.029	.023
Al^{VI}	.031	.024	.026	.011
Ti	.006	.005	.004	.004
Fe^{3+}	.015	.16	-	.013
Fe^{2+}	.472	.485	.738	.760
Mn	.027	.022	.026	.024
Mg	1.387	1.393	1.144	1.112
Ca	.060	.052	.059	.069
Na	.003	.003	.004	.005
100 Mg/(Mg+Fe+Mn)	73.0	72.7	60.0	58.3
Ca	3.1	2.7	3.0	3.5
Mg	71.7	71.6	58.9	56.9
Fe	25.2	25.7	38.0	39.6

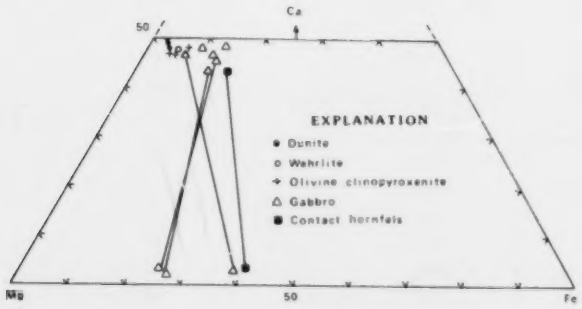


Figure 3. Compositions of pyroxene in the peridotite-gabbro suite at the Blashke Islands. Tie lines connect clinopyroxene and orthopyroxene in the same sample.

PETROGENESIS

Early investigators of Alaskan-type ultramafic complexes (Ruckmick and Noble, 1959; Taylor and Noble, 1960, 1969; Taylor, 1967) argued that the principal rock types in the complexes represent successive intrusions of a series of distinctly different ultramafic magmas. This interpretation is generally no longer accepted. The Alaskan-type ultramafic complexes are now recognized to be cumulates that originated by crystallization differentiation of basaltic magmas (Murray, 1972; Irvine, 1974). Questions remain, however, whether the parental basaltic magmas were alkaline (Irvine, 1974) or subalkaline with the resulting production of calc-alkaline liquids (Murray, 1972).

In the case of the Blashke Islands peridotite-gabbro suite, the data strongly suggest that the parental magma was subalkaline in composition. The crystallization order of minerals in the ultramafic rocks, as indicated by the succession of cumulus phases in the principal rock types, was olivine + minor chromite (dunite and wehrlite) followed by olivine + clinopyroxene ± minor chromite (olivine clinopyroxene). This sequence is the same as that of other Alaskan-type ultramafic complexes (Irvine, 1974), but it is not diagnostic of either alkaline or subalkaline magma fractionation trends, as it can occur in both. Notably absent in the Blashke Islands sequence of rocks but present in other Alaskan-type ultramafic complexes such as at Duke Island, Union Bay, Klukwan, Snettisham, and Percy Islands in Alaska and Tulameen in British Columbia are magnetite+clinopyroxene cumulates (magnetite-rich clinopyroxenites). Irvine (1974) argued that these cumulates could be a result of crystallization from a magma of low silica activity, and thus represent fractionation along an alkaline trend. Instead, in the Blashke Islands intrusion the crystallization of olivine clinopyroxenite is followed by crystallization of gabbro; much of the gabbro contains orthopyroxene and clinopyroxene and also commonly contains interstitial quartz, indicating fractionation along a subalkaline, silica-saturated trend.

Two-pyroxene gabbros also occur at Duke Island, Alaska (fig. 1), but field evidence clearly indicates that they are older than the ultramafic complex (Irvine, 1974). At Blashke Islands, however, there is no field evidence that indicates the outer zone of gabbro is of a different age than the ultramafic rocks. On the contrary (1) the spatial distribution of rock types in the gabbro zone—pyroxene-bearing gabbro near the contact with olivine clinopyroxenite, gradationally progressing to hornblende gabbro at the periphery; (2) the regular decrease in Mg/(Mg+Fe) ratio in minerals in the dunite, olivine clinopyroxenite, and gabbro; and (3) the occurrence of trace amounts of postcumulus orthopyroxene and plagioclase in some ultramafic rocks all indicate that the gabbro is genetically related to the ultramafic rocks by crystallization differentiation. The above evidence, as well as the clinopyroxene compositions, makes the Blashke Islands peridotite-gabbro suite more like the zoned mafic complex at Emigrant Gap, California, than it is like other Alaskan-type ultramafic complexes. However, the Emigrant Gap mafic complex is further differenti-

Table 5. Chemical compositions and structural formulas of hornblende in the peridotite-gabbro suite at the Blashke Islands.

[Total iron as FeO; Fe^{3+}, Fe^{2+}, Fe_2O_3, and FeO determined by the procedures outlined by Robinson and others (1982). n.d., not determined. g, green rim, b, brown core]

	Olivine clinopyroxenite		Gabbro					
Sample No.	14	49	15	29	19g	19b	17	28
SiO_2	43.1	43.6	43.1	44.1	50.8	43.4	45.3	43.1
Al_2O_3	12.2	11.7	13.2	11.3	5.43	11.8	9.46	11.6
TiO_2	1.00	2.73	2.67	2.19	.88	2.57	1.81	2.16
FeO	8.46	11.5	11.6	12.5	13.5	13.6	14.4	15.6
MnO	.10	.23	.30	.38	.52	.42	.40	.26
MgO	16.2	14.2	13.6	13.3	14.4	12.5	12.7	12.0
CaO	12.5	12.0	11.9	11.8	11.8	11.2	11.9	11.6
Na_2O	1.58	2.35	2.52	2.29	.99	2.26	1.44	2.43
K_2O	.50	n.d.	.40	.55	.50	.49	.72	n.d.
Sum	97.64	98.31	99.29	98.41	98.82	98.24	98.13	98.75
FeO	4.72	7.06	9.75	10.9	11.8	11.1	12.2	12.0
Fe_2O_3	4.14	4.93	2.03	1.73	1.90	2.81	2.50	4.02
New Sum	98.04	98.80	99.47	98.54	99.02	98.55	98.43	99.17
				Formula				
Si	6.430	6.272	6.193	6.421	7.284	6.340	6.643	6.291
Al^{IV}	1.570	1.728	1.808	1.579	.716	1.660	1.357	1.709
T	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000
Al^{VI}	.476	.253	.429	.361	.202	.370	.274	.292
Ti	.108	.296	.289	.240	.095	.282	.200	.239
Fe^{3+}	.444	.533	.220	.190	.205	.309	.276	.442
Fe^{2+}	.532	.849	1.146	1.322	1.416	1.318	1.477	1.431
Mn	-	.028	-	-	.003	-	-	-
Mg	3.440	3.040	2.916	2.887	3.079	2.721	2.773	2.618
C	5.000	4.999	5.000	5.000	5.000	5.000	5.000	5.000
Fe^{2+}	.031	-	.029	.010	-	.037	.012	.032
Mn	.013	-	.036	.047	.060	.050	.050	.032
Ca	1.909	1.848	1.835	1.842	1.816	1.753	1.869	1.818
Na	.047	.152	.100	.101	.124	.160	.069	.118
B	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Na	.389	.502	.603	.546	.151	.481	.341	.571
K	.092	n.d.	.074	.103	.092	.092	.135	-
A	.481	.502	.677	.649	.243	.573	.476	.571
$\frac{100\ Mg}{(Mg+Fe^{2+}+Mn)}$	85.7	77.6	70.7	67.7	67.6	65.9	64.3	63.7

Table 6. Chemical compositions and structural formulas of plagioclase in the peridotite-gabbro suite at the Blashke Islands.

[Total iron as Fe_2O_3. n.d., not determined]

	Gabbro					
Sample No.	49	15	17	28	29	19
SiO_2	48.1	47.1	48.7	50.2	49.4	53.8
Al_2O_3	33.6	33.5	32.4	32.6	31.9	29.2
Fe_2O_3	n.d.	.45	.48	n.d.	.37	.16
MgO	n.d.	.06	.06	n.d.	.07	.04
CaO	17.2	17.4	16.0	15.1	15.3	11.6
Na_2O	2.03	2.10	2.82	3.16	3.26	5.37
K_2O	.04	.10	.12	.06	.04	.18
Sum	100.97	100.71	100.58	101.12	100.34	100.35
	Formula per 20 cations					
Si	8.736	8.575	8.846	9.045	8.970	9.653
Al	7.192	7.188	6.937	6.923	6.827	6.175
Fe^{3+}	n.d.	.062	.066	n.d.	.051	.022
Mg	n.d.	.016	.016	n.d.	.019	.011
Ca	3.347	3.394	3.114	2.915	2.977	2.230
Na	.715	.741	.993	1.104	1.148	1.868
K	.009	.023	.028	.014	.009	.041
An	82.2	81.6	75.3	72.3	72.0	53.9
Ab	17.6	17.8	24.0	27.4	27.8	45.1
Or	.2	.6	.7	.3	.2	1.0

ated to yield appreciable diorite, tonalite, and granodiorite (James, 1971). The suppression of crystallization of substantial amounts of orthopyroxene and plagioclase in the ultramafic rocks might be due to an elevated P_{H_2O} in the magma (Murray, 1972; Allen and Boettcher, 1978).

Several authors (Kushiro, 1960; LeBas, 1962; Nisbet and Pearce, 1977; Leterrier and others, 1982) have been successful in relating the chemical composition of igneous clinopyroxenes to the chemical nature of their host rocks. Clinopyroxenes that crystallized from alkaline magmas differ from those that crystallized from subalkaline magmas by generally having higher contents of calcium, titanium, and aluminum. The proportions of titanium and aluminum in clinopyroxene increase as the host magma changes from subalkaline through alkaline to peralkaline. The aluminum and titanium contents in clinopyroxene in the Blashke Islands intrusion are appreciably lower than in clinopyroxene in the Duke Island, Union Bay, and Tulameen ultramafic complexes. Plotting the compositions of clinopyroxene in SiO_2 versus Al_2O_3 and Al^{IV} versus TiO_2 diagrams (figs. 4 and 5) shows that all the Blashke Islands clinopyroxenes and most of the Duke Island clinopyroxenes fall within the field of subalkaline rocks as defined by LeBas (1962), although the Duke Island clinopyroxenes clearly trend toward more alkaline compositions. Clinopyroxene compositions plotted on the (Ca+Na) versus Ti discrimination diagram of Leterrier and others (1982) (fig. 6) fall in an area of low counting frequency overlap of the subalkaline and alkaline basalt fields and are thus equivocal.

Table 7. Chemical compositions and structural formulas of chromite in the peridotite-gabbro suite at the Blashke Islands.

[Total iron was determined, Fe_2O_3, FeO, Fe^{3+}, and Fe^{2+} calculated by assuming stoichiometry]

	Dunite						Wehrlite	Olivine clinopyroxenite
Sample No.	37	5	6	43	10	12	44	13
Cr_2O_3	45.8	43.6	40.2	38.9	31.6	30.1	28.8	33.4
Al_2O_3	12.0	11.9	11.2	11.4	20.0	18.6	18.7	16.4
TiO_2	.38	.44	.37	.44	.60	.96	.83	.58
Fe_2O_3	13.2	15.2	18.2	19.9	17.5	19.8	20.5	17.4
FeO	17.7	18.7	20.8	21.2	20.6	21.8	22.6	24.5
MnO	1.26	1.40	1.29	1.27	1.03	1.23	1.12	1.19
MgO	9.93	9.03	7.71	7.72	9.38	8.38	7.85	5.76
Sum	100.27	100.27	99.97	100.83	100.71	100.87	100.40	99.23
	Formula per 3 cations							
Cr	1.190	1.141	1.070	1.027	0.795	0.767	0.739	0.886
Al	.465	.464	.444	.449	.750	.706	.715	.649
Ti	.009	.011	.014	.011	.014	.023	.020	.015
Fe^{3+}	.327	.380	.460	.500	.420	.480	.500	.440
Fe^{2+}	.487	.519	.587	.592	.548	.587	.615	.688
Mn	.035	.039	.037	.036	.028	.034	.031	.034
Mg	.487	.445	.387	.384	.445	.403	.380	.288
Cr/R^{3+}	.600	.575	.542	.520	.405	.393	.378	.449
Al/R^{3+}	.235	.234	.225	.227	.382	.361	.366	.329
Fe^{3+}/R^{3+}	.165	.191	.233	.253	.214	.246	.256	.223
$Mg/(Mg+Fe^{2+})$	.500	.462	.397	.393	.448	.407	.382	.295

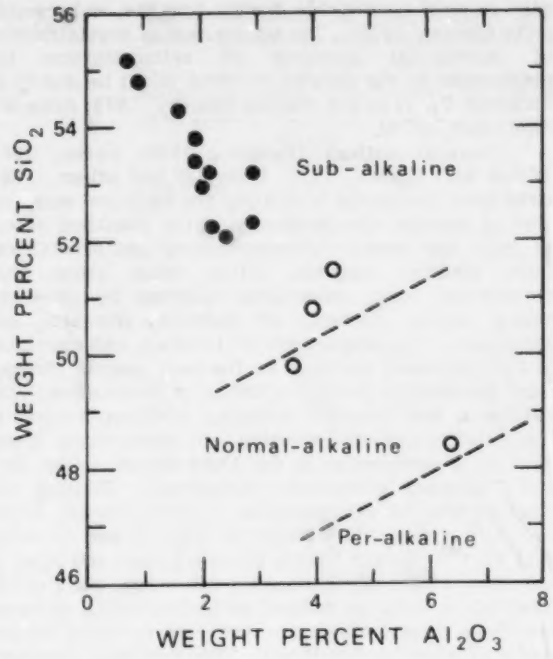


Figure 4. SiO_2 versus Al_2O_3 in clinopyroxene in the Blashke Islands (dots) and Duke Island (circles, Irvine, 1974) intrusions. Compositional field boundaries (dashed lines from LeBas (1962).

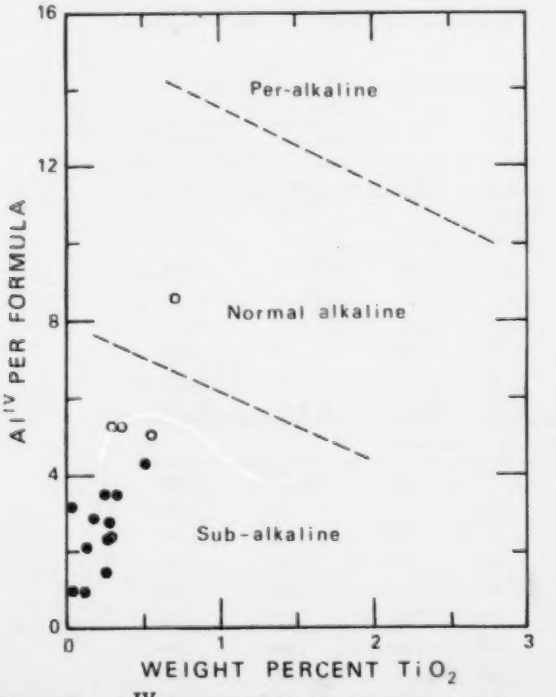


Figure 5. Al^{IV} versus TiO_2 in clinopyroxene in the Blashke Islands (dots) and Duke Island (circles, Irvine, 1974) intrusions. Compositional field boundaries (dashed lines from LeBas (1962).

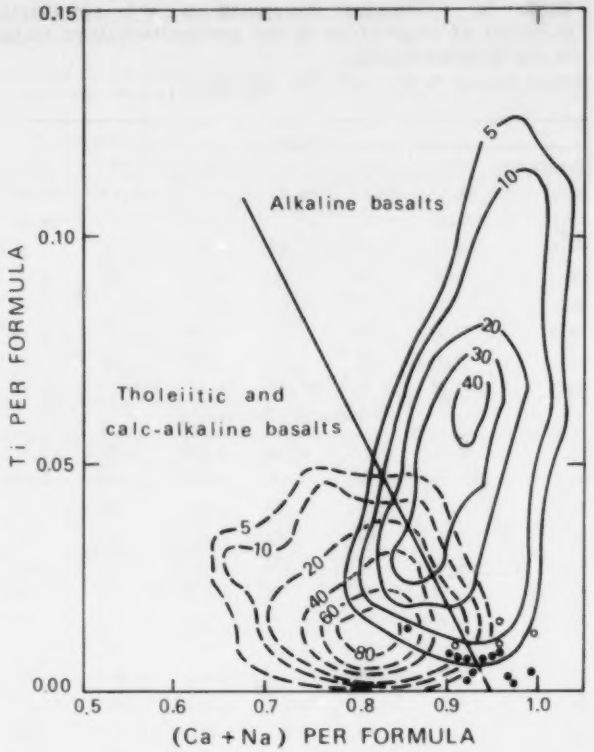


Figure 6. Ti versus (Ca+Na) in clinopyroxene in the Blashke Islands (dots) and Duke Island (circles, Irvine, 1974) intrusions. Counting frequency curves (contours) and compositional field boundary (straight line) are from Leterrier and others (1982).

Collectively the field, petrographic, and mineral chemistry data indicate that the parent magma of the Blashke Islands peridotite-gabbro suite was subalkaline and significantly dissimilar from the parent magma that crystallized the Duke Island, Union Bay, and Tulameen ultramafic complexes, and probably other Alaskan-type ultramafic complexes. The data also suggest, as proposed by Irvine (1974) for Alaskan-type complexes in general, that the Blashke Islands peridotite-gabbro suite accumulated as a stratiform body by crystallization differentiation in a subvolcanic magma chamber and achieved its concentric-zoned structure by upward diapiric emplacement. The occurrence of Alaskan-type complexes that crystallized from parent magmas of different compositions is compatible with the occurrence of volcanic rocks in southeastern Alaska of subalkaline and alkaline compositions (Brew and others, 1966; Brew, 1968; Berg and others, 1972; Irvine, 1973; Ford and Brew, 1977).

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